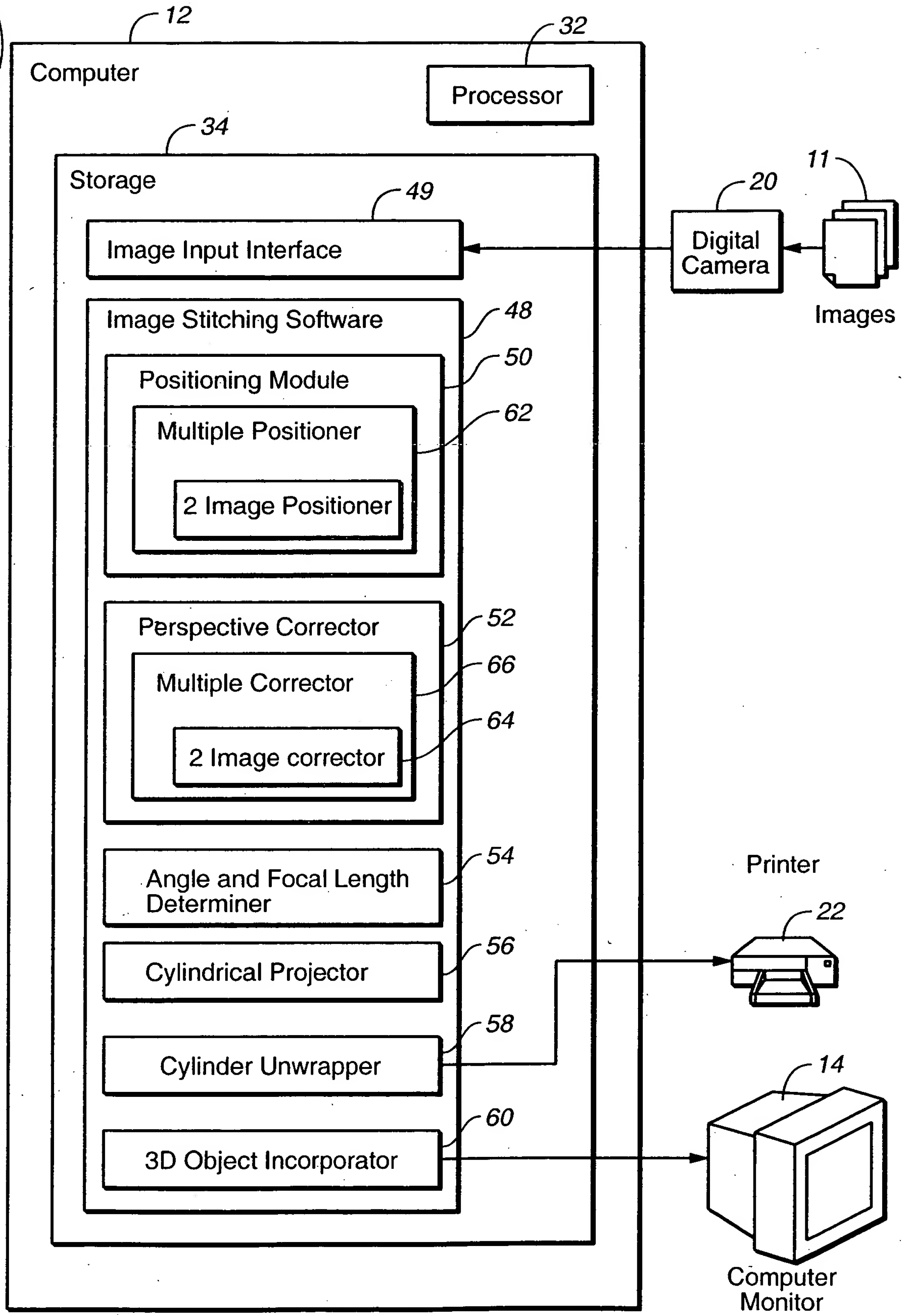
12
Computer
32
Processor
34
Storage
49
Image Input Interface
Image Stitching Software
48
Positioning Module
50
Multiple Positioner
62
2 Image Positioner
Perspective Corrector
52
Multiple Corrector
66
2 Image corrector
64
Angle and Focal Length Determiner
54
Cylindrical Projector
56
Cylinder Unwrapper
58
3D Object Incorporator
60
20
Digital Camera
11
Images
Printer
22
14
Computer Monitor

FIG._1

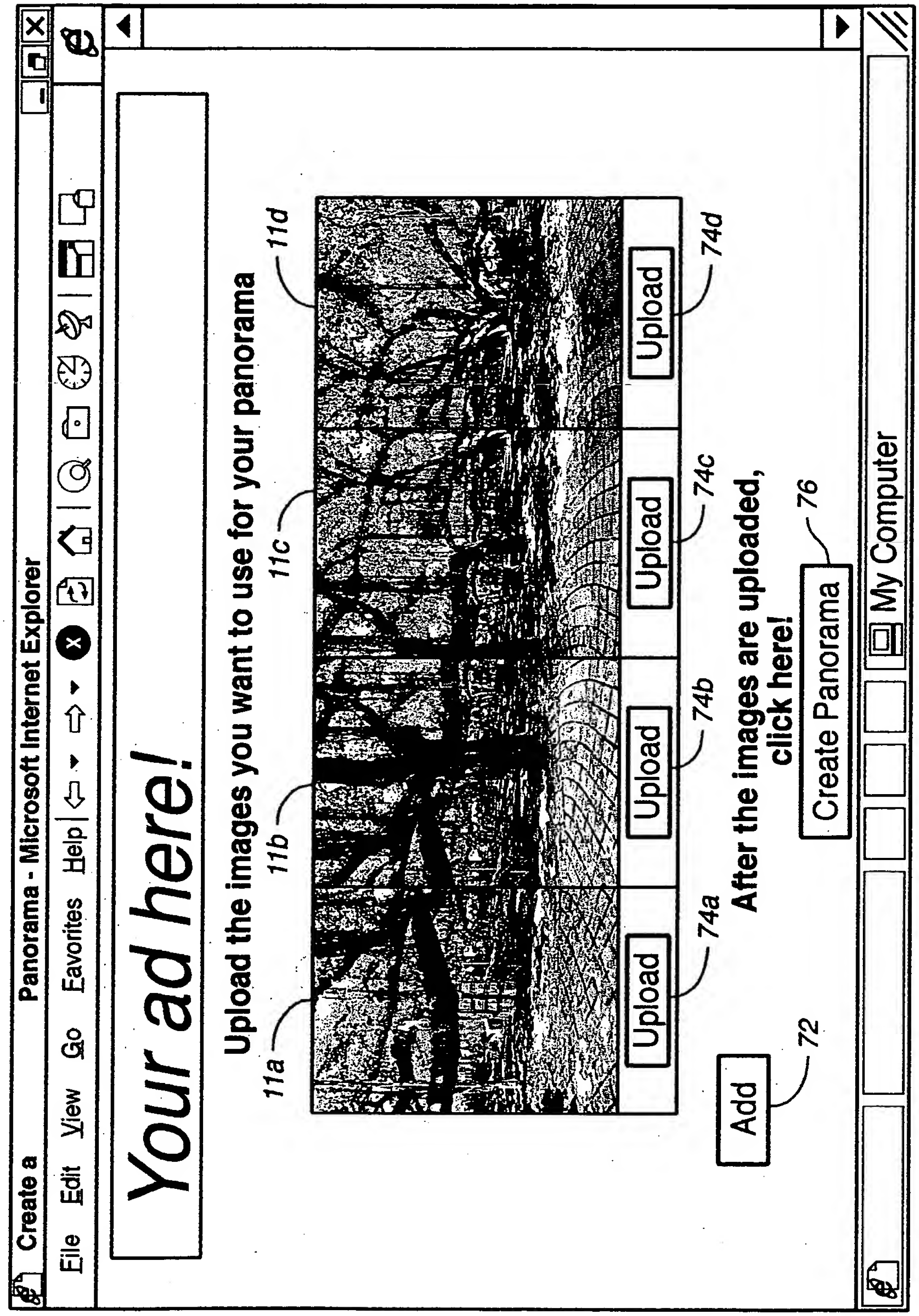
Create a Panorama - Microsoft Internet Explorer
File Edit View Go Favorites Help
Your ad here!
Upload the images you want to use for your panorama
11a
11b
11c
11d
Upload
Upload
Upload
Upload
74a
74b
74c
74d
Add
72
After the images are uploaded, click here!
Create Panorama
76
My Computer
70

FIG._2A

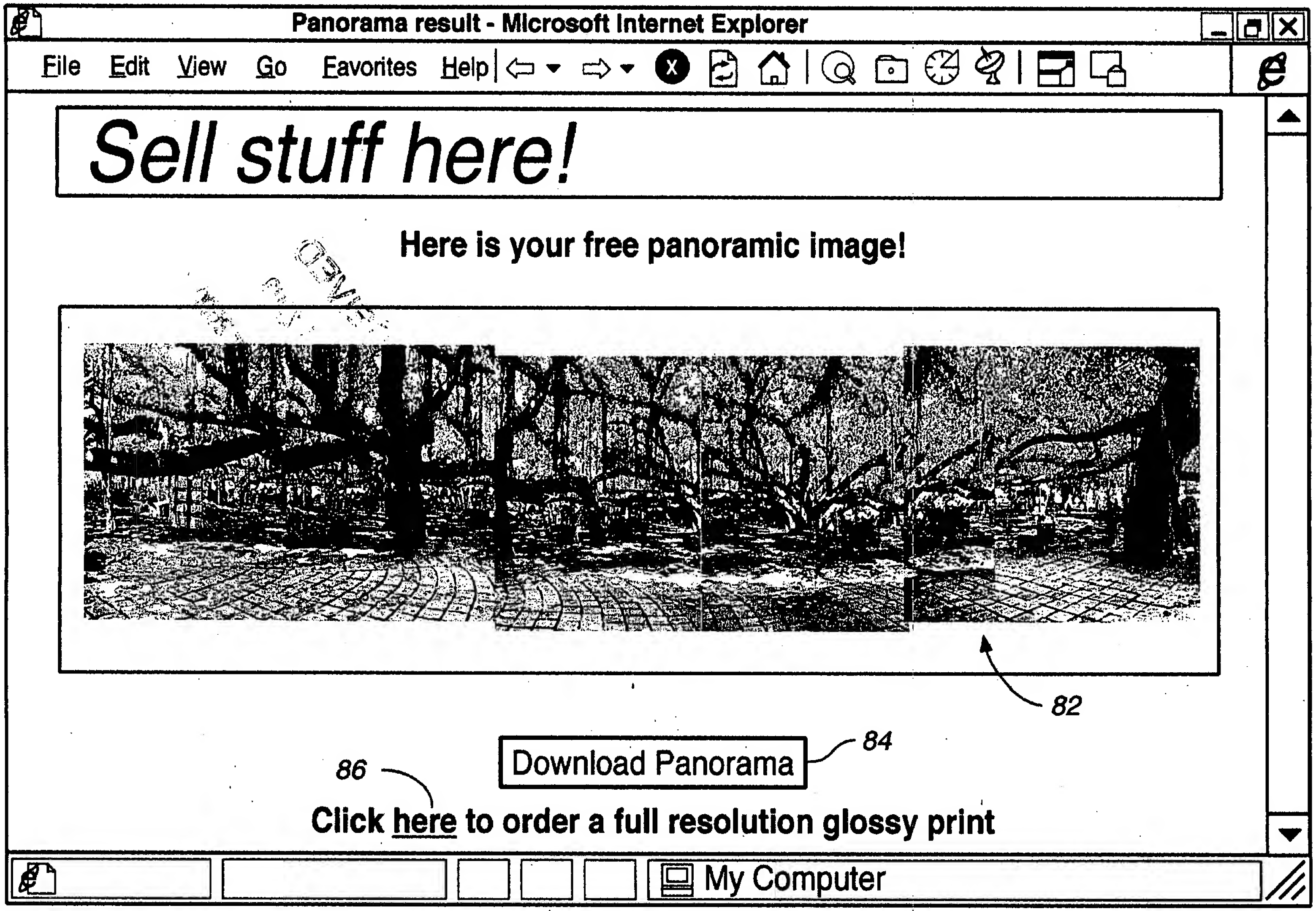
Panorama result - Microsoft Internet Explorer
File Edit View Go Favorites Help
Sell stuff here!
Here is your free panoramic image!
82
Download Panorama
84
86
Click here to order a full resolution glossy print
My Computer
80

FIG._2B

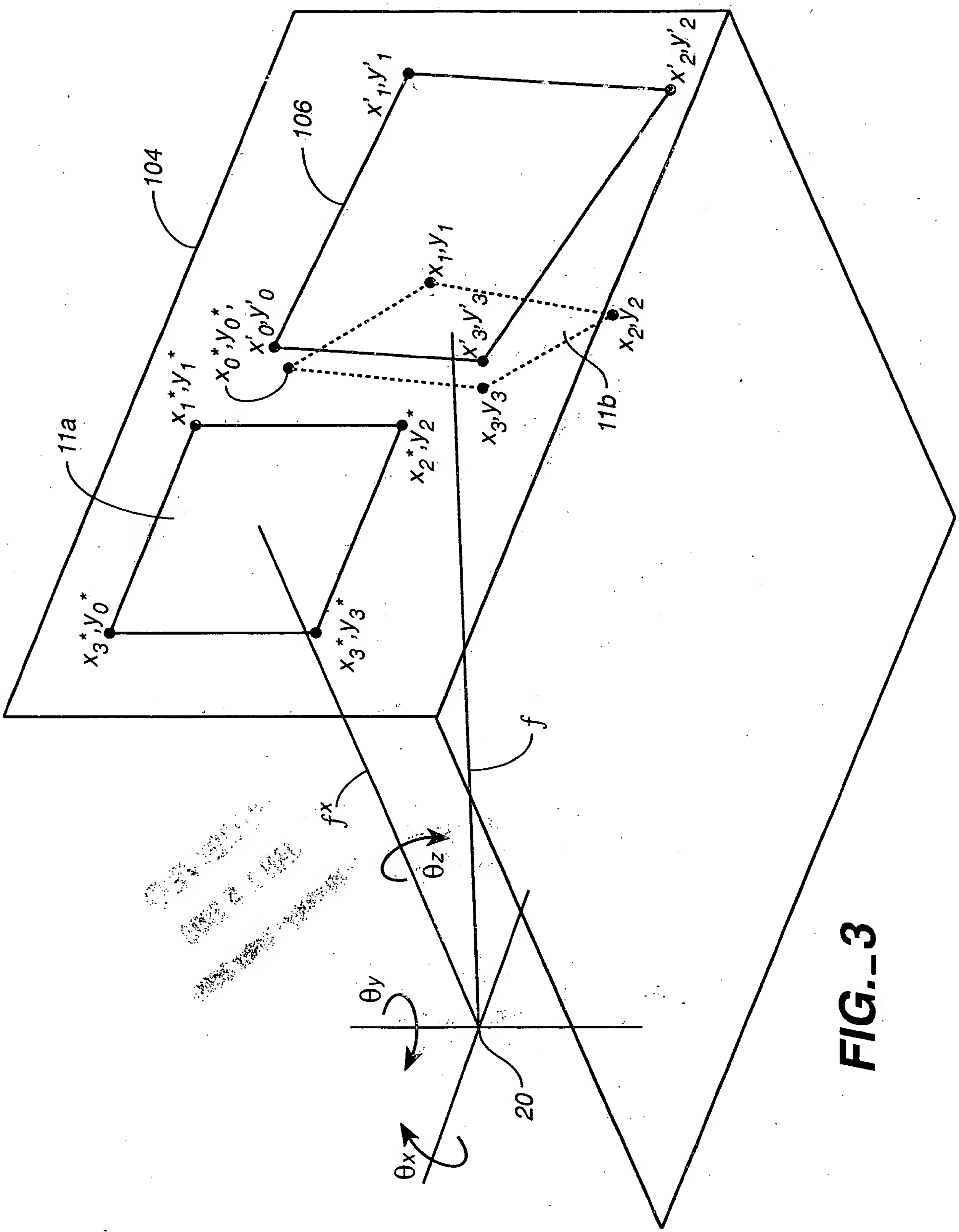
104
106
11a
11b
20
x'_1,y'_1
x'_2,y'_2
x_1,y_1
$x_0^*,y_0^*,$
x'_0,y'_0
x'_3,y'_3
x_2,y_2
x_1^*,y_1^*
x_3,y_3
x_2^*,y_2^*
x_3^*,y_0^*
x_3^*,y_3^*
f
f^x
θz
θy
θx

FIG._3

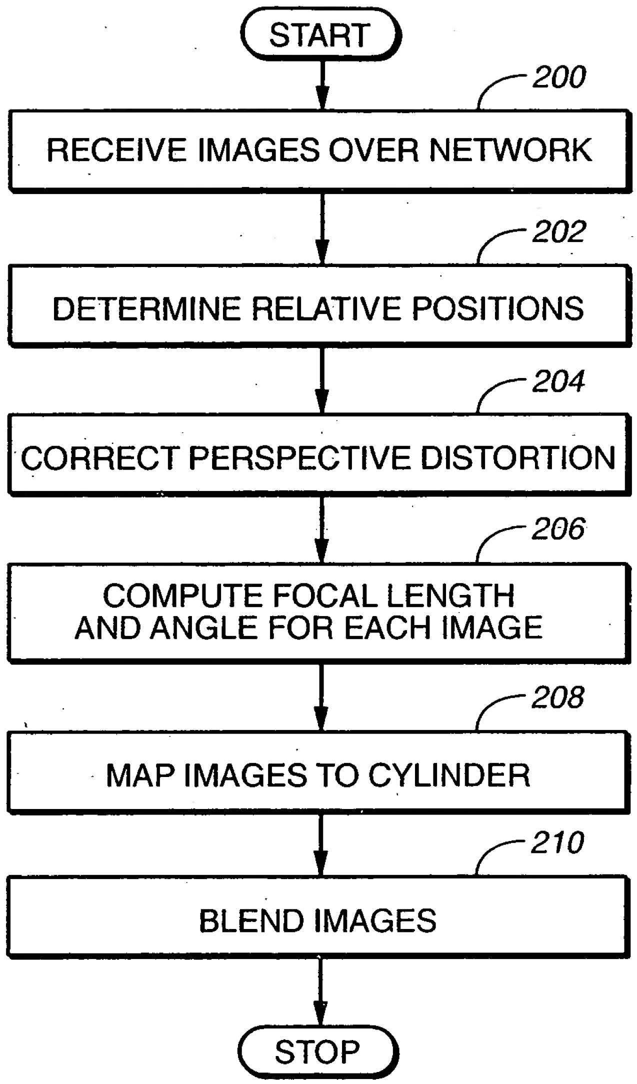
START
200
RECEIVE IMAGES OVER NETWORK
202
DETERMINE RELATIVE POSITIONS
204
CORRECT PERSPECTIVE DISTORTION
206
COMPUTE FOCAL LENGTH
AND ANGLE FOR EACH IMAGE
208
MAP IMAGES TO CYLINDER
210
BLEND IMAGES
STOP

FIG._4

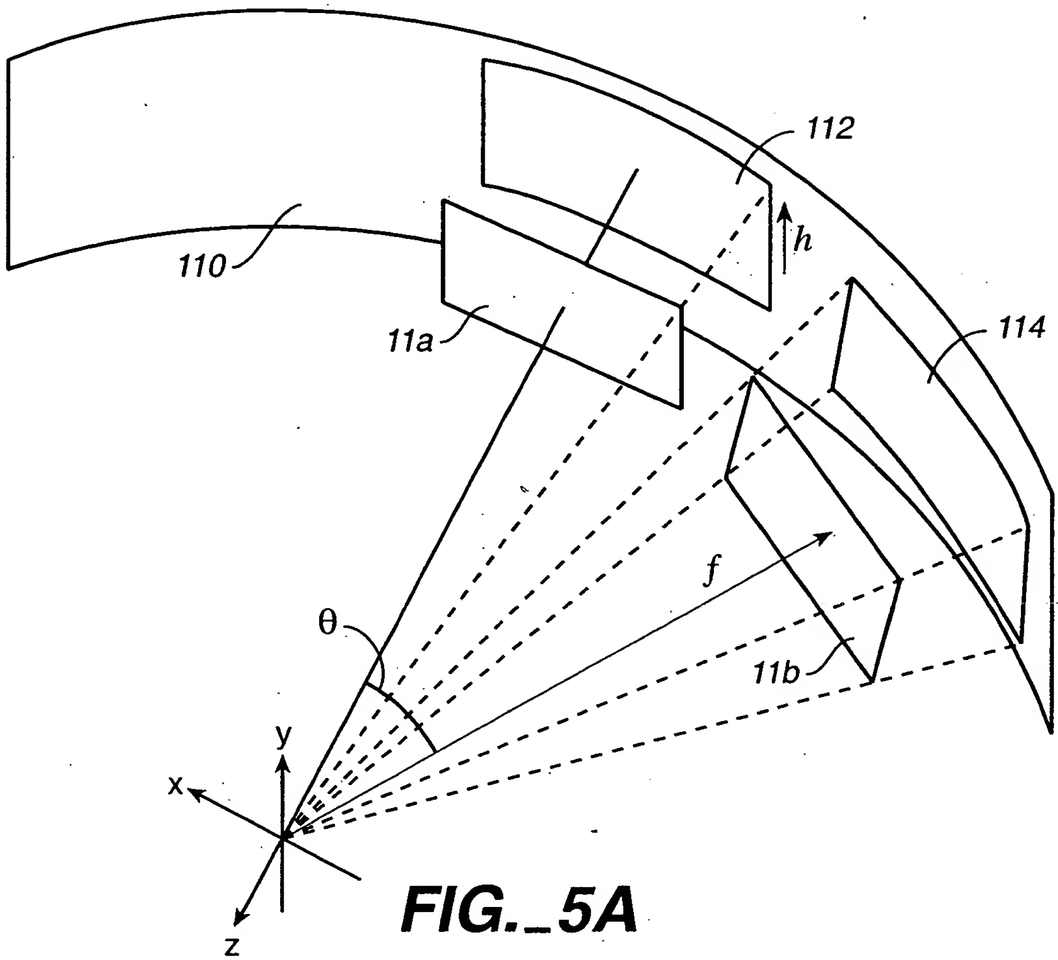

FIG._5A

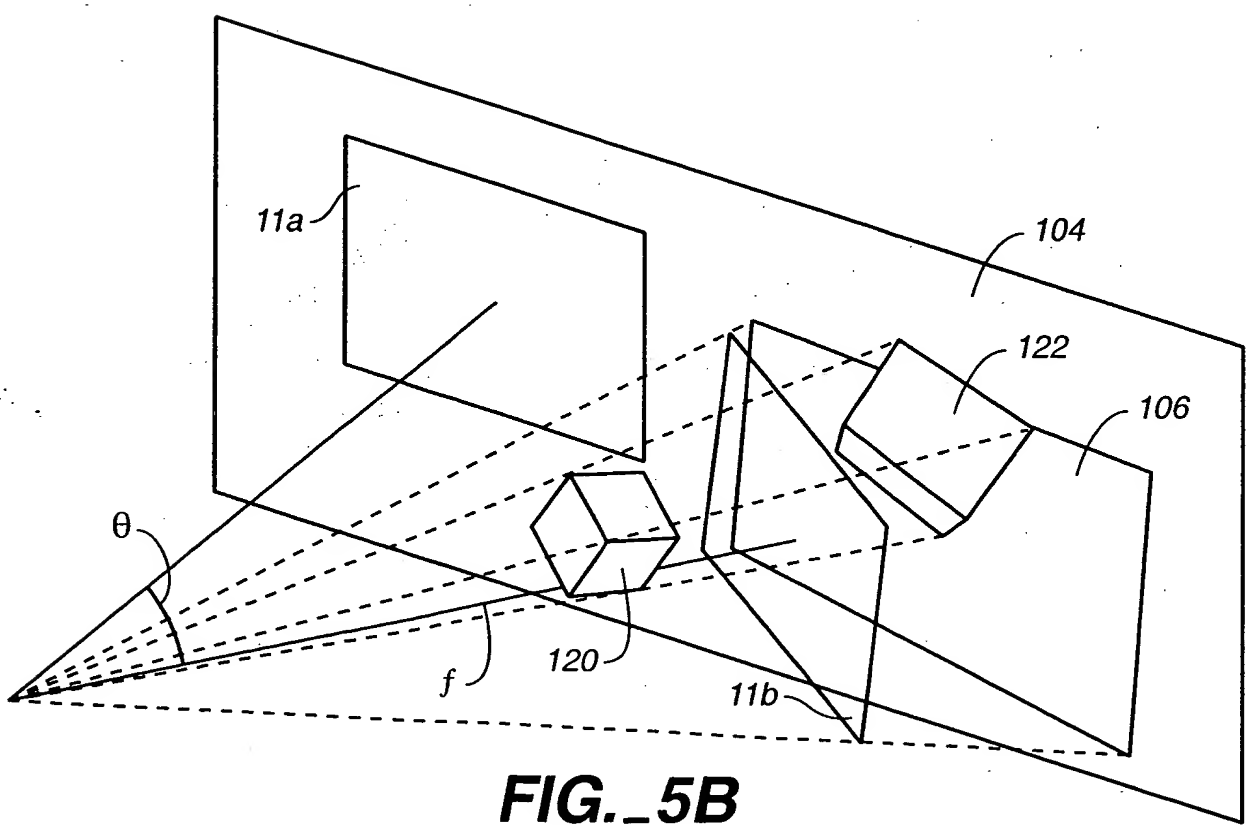

FIG._5B

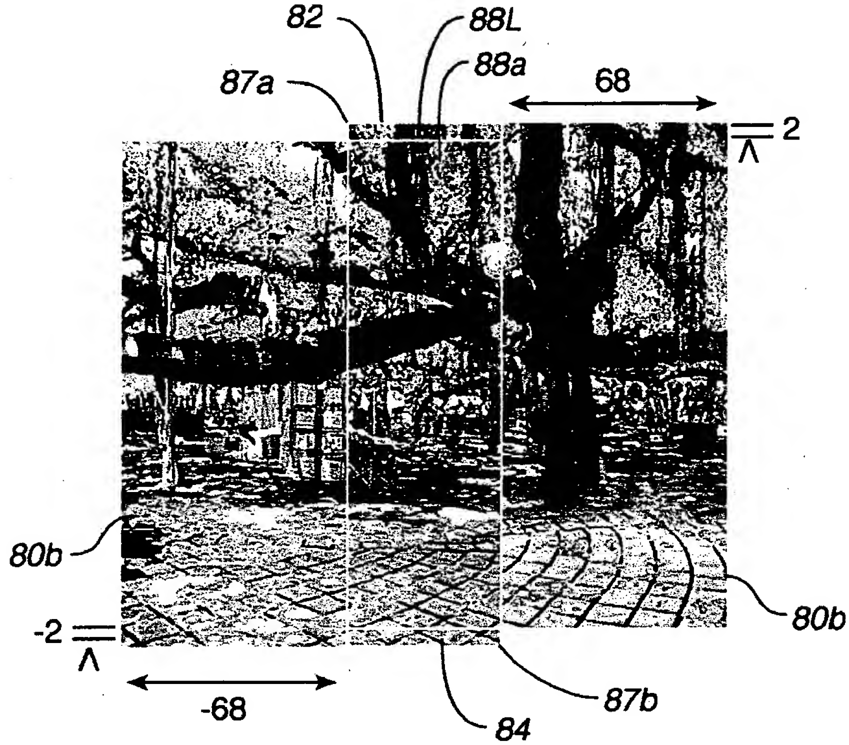

FIG._6A

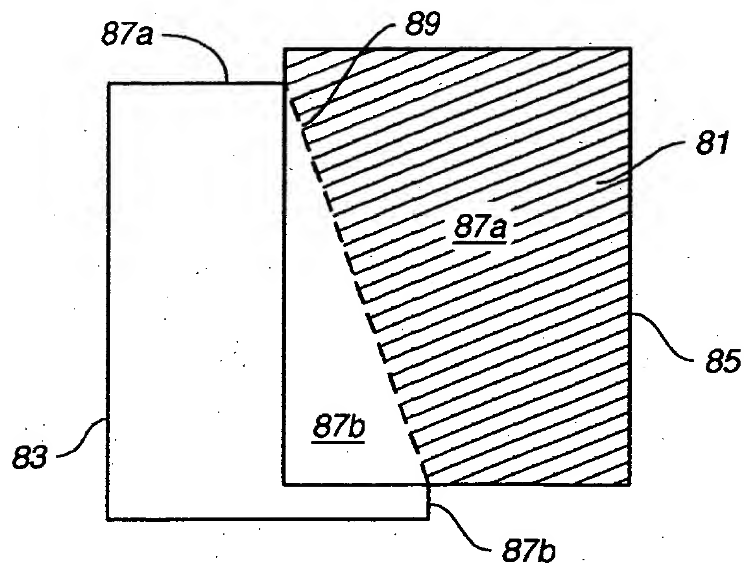

FIG._6F

FIG._6B

80A 80B 80C 80D 80E 80F

Adjacent Lists

86A	86B	86C	86D	86E	86F
B: 68, 2	A: -68, -2 C: 69, 4	B: -69, -4 D: 66, -1	C: -66, -1 E: 66, -1	D: -66, 1 E: 67, -2	E: -67, 2

FIG._6C

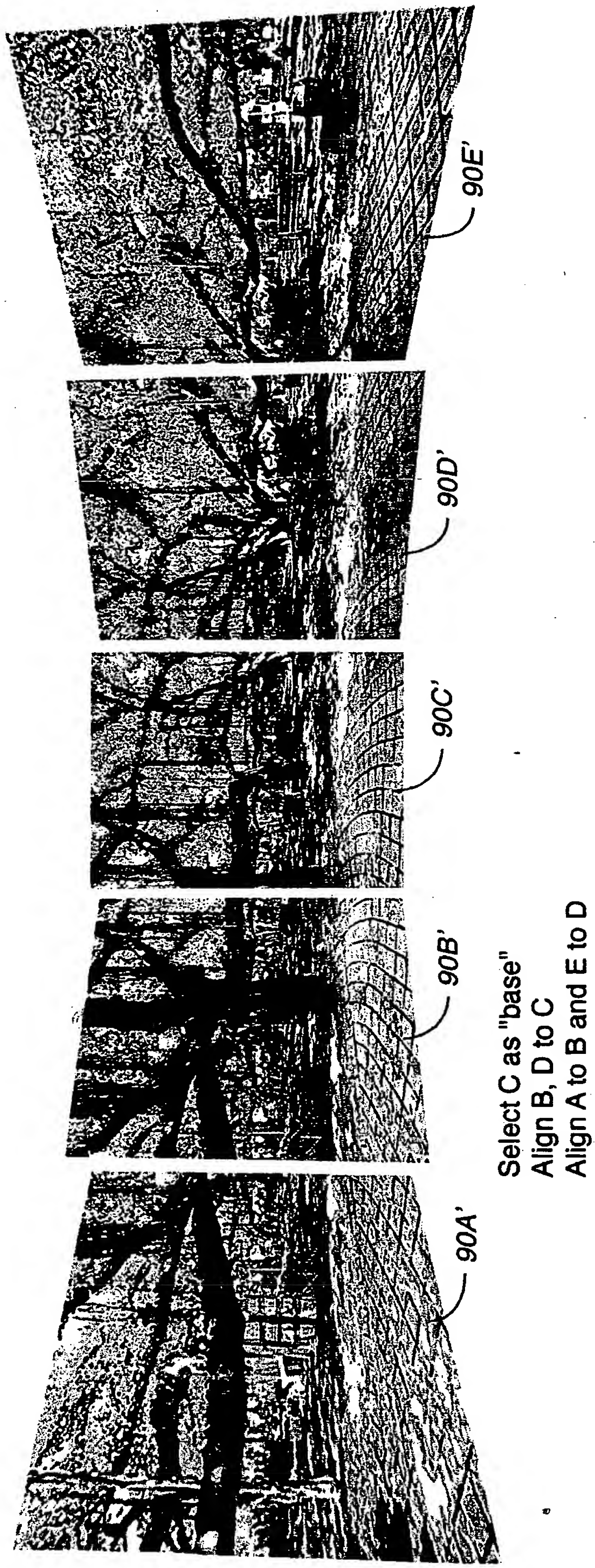
90E'
90D'
90C'
90B'
90A'
Select C as "base"
Align B, D to C
Align A to B and E to D

FIG._6D

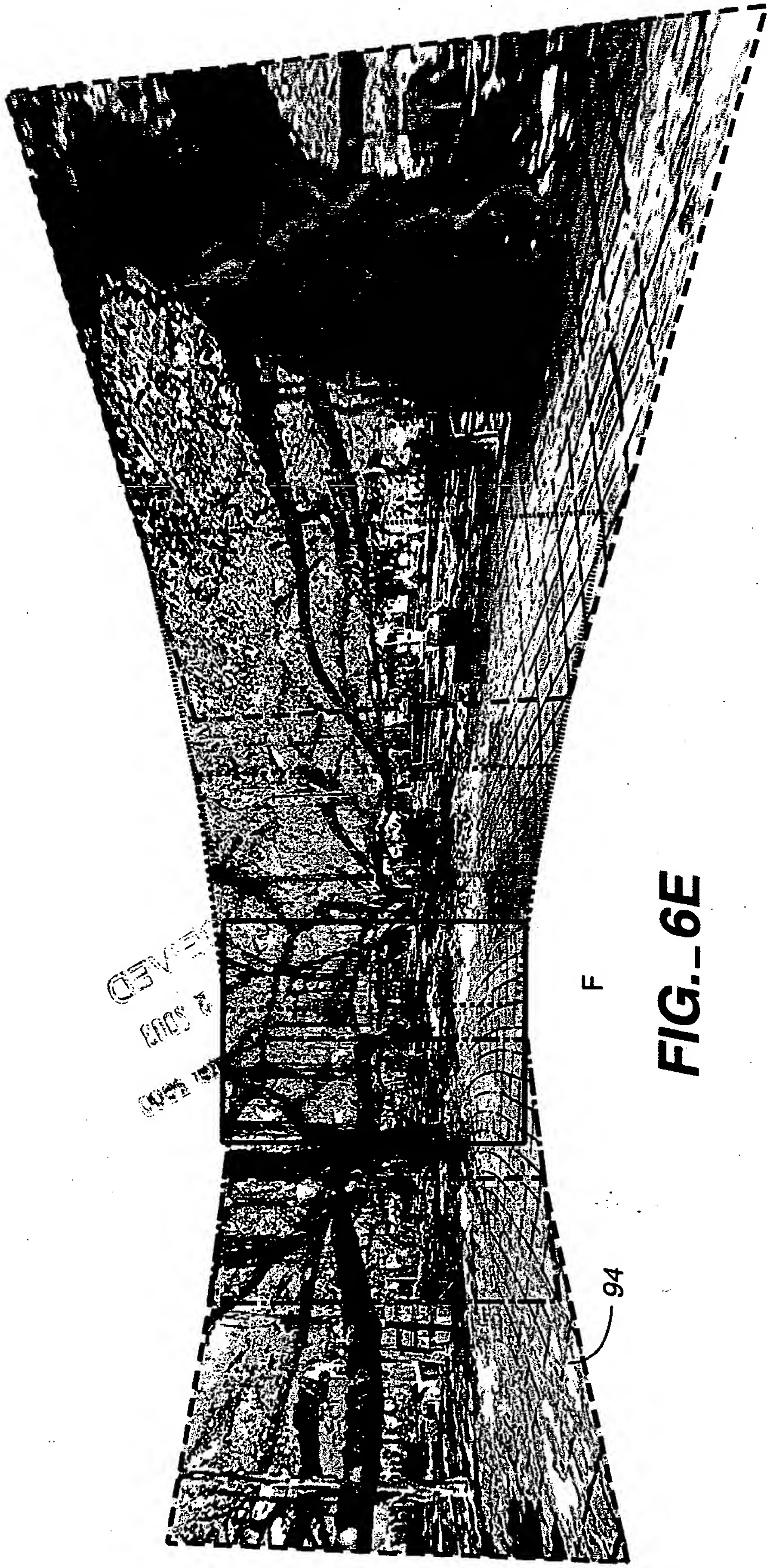

FIG._6E

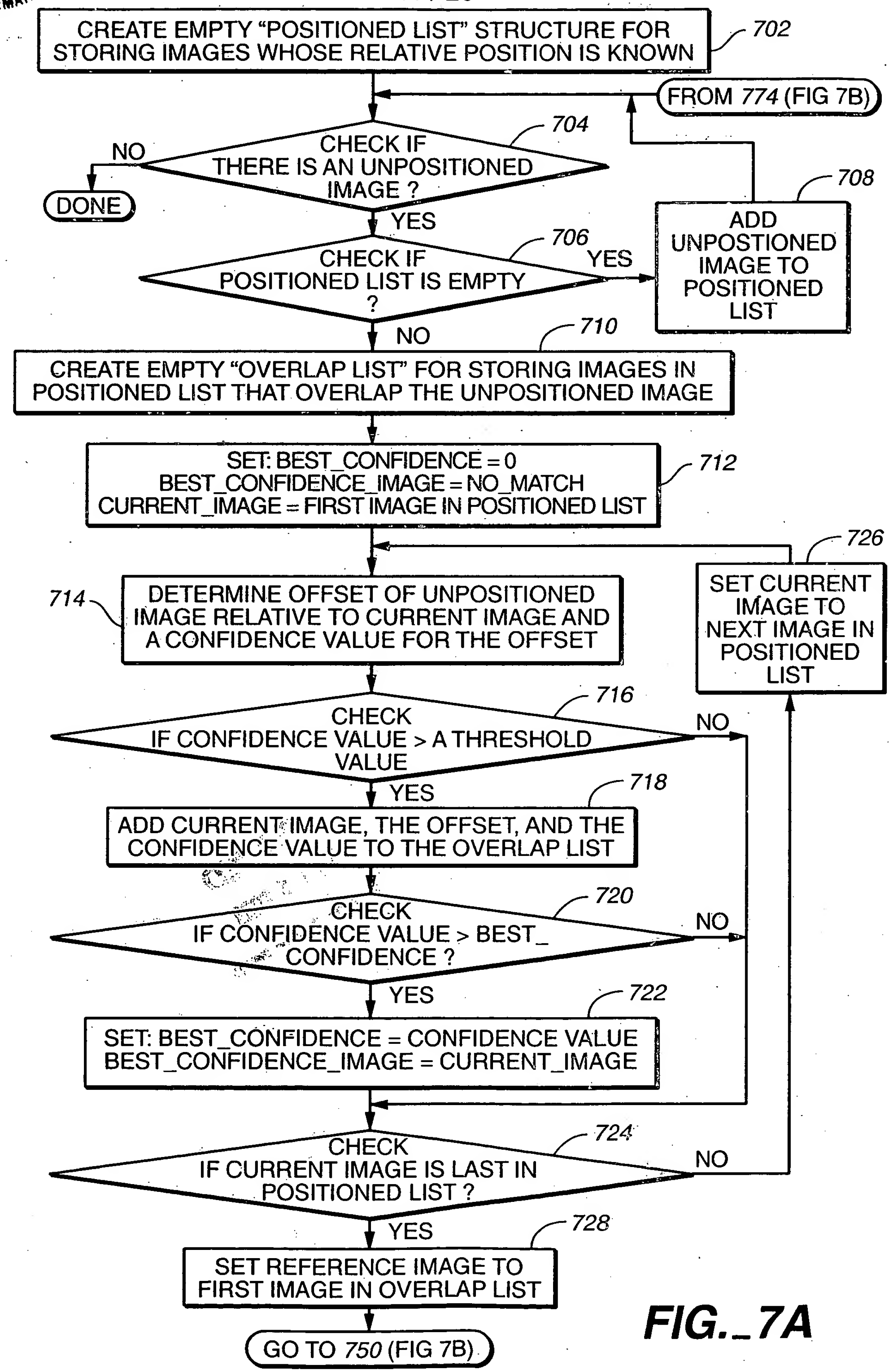
CREATE EMPTY "POSITIONED LIST" STRUCTURE FOR STORING IMAGES WHOSE RELATIVE POSITION IS KNOWN
702
FROM 774 (FIG 7B)
CHECK IF THERE IS AN UNPOSITIONED IMAGE ?
704
NO
DONE
YES
ADD UNPOSTIONED IMAGE TO POSITIONED LIST
708
CHECK IF POSITIONED LIST IS EMPTY ?
706
YES
NO
710
CREATE EMPTY "OVERLAP LIST" FOR STORING IMAGES IN POSITIONED LIST THAT OVERLAP THE UNPOSITIONED IMAGE
SET: BEST_CONFIDENCE = 0
BEST_CONFIDENCE_IMAGE = NO_MATCH
CURRENT_IMAGE = FIRST IMAGE IN POSITIONED LIST
712
726
SET CURRENT IMAGE TO NEXT IMAGE IN POSITIONED LIST
714
DETERMINE OFFSET OF UNPOSITIONED IMAGE RELATIVE TO CURRENT IMAGE AND A CONFIDENCE VALUE FOR THE OFFSET
CHECK IF CONFIDENCE VALUE > A THRESHOLD VALUE
716
NO
YES
718
ADD CURRENT IMAGE, THE OFFSET, AND THE CONFIDENCE VALUE TO THE OVERLAP LIST
CHECK IF CONFIDENCE VALUE > BEST_ CONFIDENCE ?
720
NO
YES
722
SET: BEST_CONFIDENCE = CONFIDENCE VALUE
BEST_CONFIDENCE_IMAGE = CURRENT_IMAGE
CHECK IF CURRENT IMAGE IS LAST IN POSITIONED LIST ?
724
NO
YES
728
SET REFERENCE IMAGE TO FIRST IMAGE IN OVERLAP LIST
GO TO 750 (FIG 7B)

FIG._7A

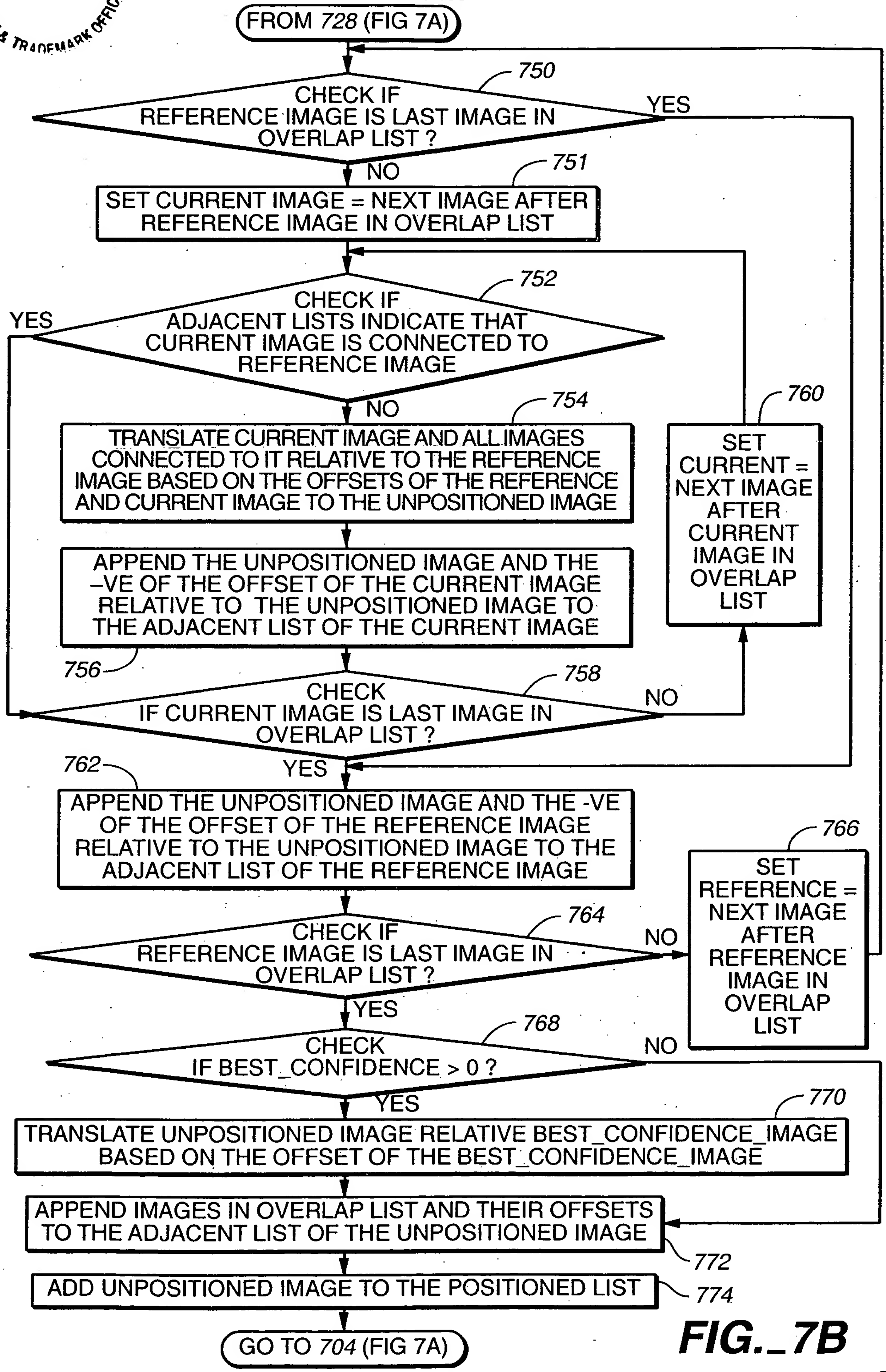
FROM 728 (FIG 7A)
750
CHECK IF REFERENCE IMAGE IS LAST IMAGE IN OVERLAP LIST ?
YES
NO
751
SET CURRENT IMAGE = NEXT IMAGE AFTER REFERENCE IMAGE IN OVERLAP LIST
752
CHECK IF ADJACENT LISTS INDICATE THAT CURRENT IMAGE IS CONNECTED TO REFERENCE IMAGE
YES
NO
754
TRANSLATE CURRENT IMAGE AND ALL IMAGES CONNECTED TO IT RELATIVE TO THE REFERENCE IMAGE BASED ON THE OFFSETS OF THE REFERENCE AND CURRENT IMAGE TO THE UNPOSITIONED IMAGE
760
SET CURRENT = NEXT IMAGE AFTER CURRENT IMAGE IN OVERLAP LIST
APPEND THE UNPOSITIONED IMAGE AND THE –VE OF THE OFFSET OF THE CURRENT IMAGE RELATIVE TO THE UNPOSITIONED IMAGE TO THE ADJACENT LIST OF THE CURRENT IMAGE
756
758
CHECK IF CURRENT IMAGE IS LAST IMAGE IN OVERLAP LIST ?
NO
762
YES
APPEND THE UNPOSITIONED IMAGE AND THE -VE OF THE OFFSET OF THE REFERENCE IMAGE RELATIVE TO THE UNPOSITIONED IMAGE TO THE ADJACENT LIST OF THE REFERENCE IMAGE
766
SET REFERENCE = NEXT IMAGE AFTER REFERENCE IMAGE IN OVERLAP LIST
764
CHECK IF REFERENCE IMAGE IS LAST IMAGE IN OVERLAP LIST ?
NO
YES
768
CHECK IF BEST_CONFIDENCE > 0 ?
NO
YES
770
TRANSLATE UNPOSITIONED IMAGE RELATIVE BEST_CONFIDENCE_IMAGE BASED ON THE OFFSET OF THE BEST_CONFIDENCE_IMAGE
APPEND IMAGES IN OVERLAP LIST AND THEIR OFFSETS TO THE ADJACENT LIST OF THE UNPOSITIONED IMAGE
772
ADD UNPOSITIONED IMAGE TO THE POSITIONED LIST
774
GO TO 704 (FIG 7A)

FIG._7B

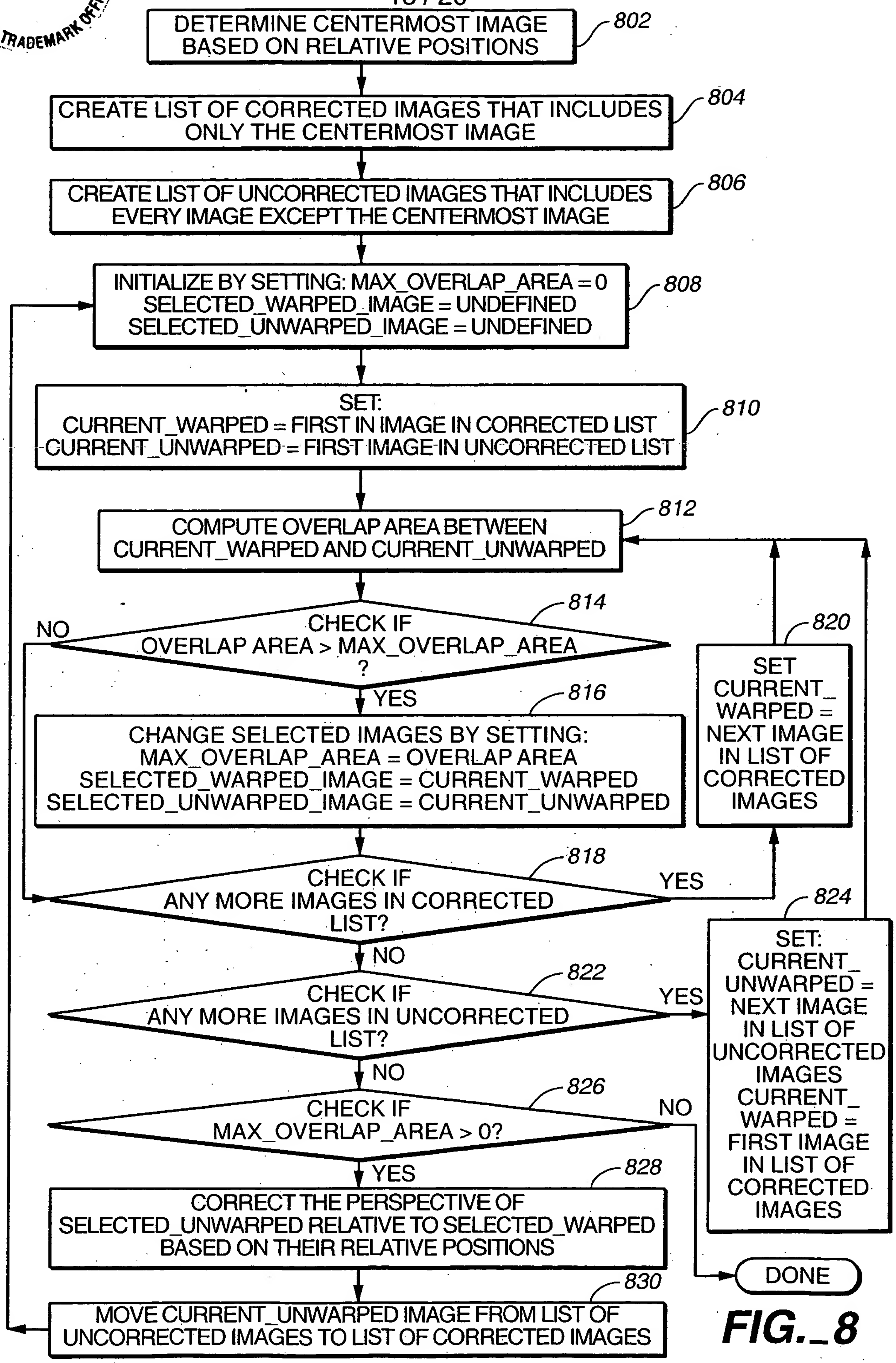
DETERMINE CENTERMOST IMAGE BASED ON RELATIVE POSITIONS
802
CREATE LIST OF CORRECTED IMAGES THAT INCLUDES ONLY THE CENTERMOST IMAGE
804
CREATE LIST OF UNCORRECTED IMAGES THAT INCLUDES EVERY IMAGE EXCEPT THE CENTERMOST IMAGE
806
INITIALIZE BY SETTING: MAX_OVERLAP_AREA = 0 SELECTED_WARPED_IMAGE = UNDEFINED SELECTED_UNWARPED_IMAGE = UNDEFINED
808
SET: CURRENT_WARPED = FIRST IN IMAGE IN CORRECTED LIST CURRENT_UNWARPED = FIRST IMAGE IN UNCORRECTED LIST
810
COMPUTE OVERLAP AREA BETWEEN CURRENT_WARPED AND CURRENT_UNWARPED
812
CHECK IF OVERLAP AREA > MAX_OVERLAP_AREA ?
814
NO
YES
CHANGE SELECTED IMAGES BY SETTING: MAX_OVERLAP_AREA = OVERLAP AREA SELECTED_WARPED_IMAGE = CURRENT_WARPED SELECTED_UNWARPED_IMAGE = CURRENT_UNWARPED
816
SET CURRENT_ WARPED = NEXT IMAGE IN LIST OF CORRECTED IMAGES
820
CHECK IF ANY MORE IMAGES IN CORRECTED LIST?
818
YES
NO
CHECK IF ANY MORE IMAGES IN UNCORRECTED LIST?
822
YES
SET: CURRENT_ UNWARPED = NEXT IMAGE IN LIST OF UNCORRECTED IMAGES CURRENT_ WARPED = FIRST IMAGE IN LIST OF CORRECTED IMAGES
824
NO
CHECK IF MAX_OVERLAP_AREA > 0?
826
NO
YES
CORRECT THE PERSPECTIVE OF SELECTED_UNWARPED RELATIVE TO SELECTED_WARPED BASED ON THEIR RELATIVE POSITIONS
828
DONE
MOVE CURRENT_UNWARPED IMAGE FROM LIST OF UNCORRECTED IMAGES TO LIST OF CORRECTED IMAGES
830

FIG._8

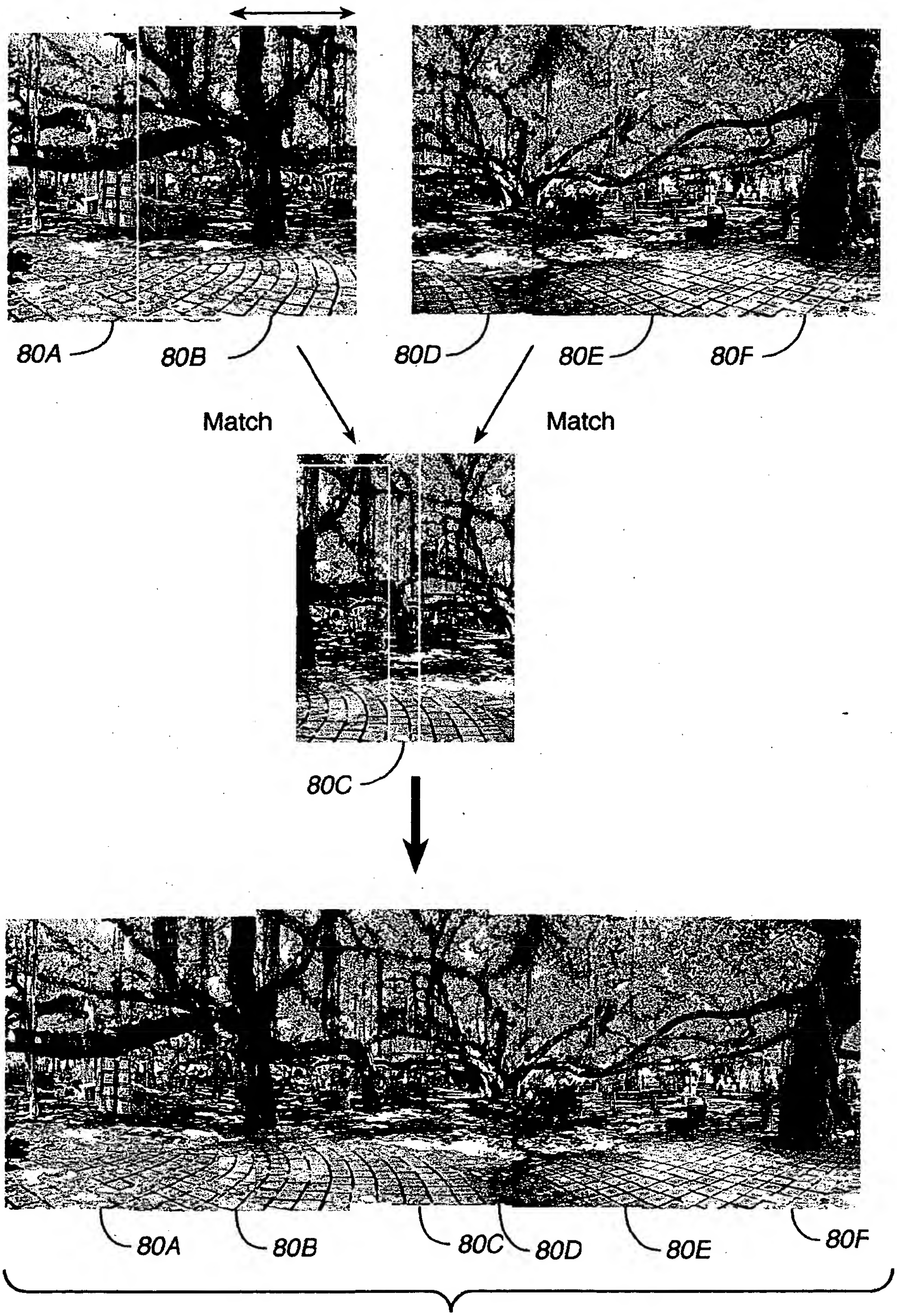

FIG._9

Original Image

	2-D coordinates	4-D coordinates
Vertex 0	(x_0, y_0)	$(x_0, y_0, 0, 1)$
Vertex 1	(x_1, y_1)	$(x_1, y_1, 0, 1)$
Vertex 2	(x_2, y_2)	$(x_2, y_2, 0, 1)$
Vertex 3	(x_3, y_3)	$(x_3, y_3, 0, 1)$
The i^{th} vertex	(x_i, y_i)	$(x_i, y_i, 0, 1)$

134

130 132

FIG._10A

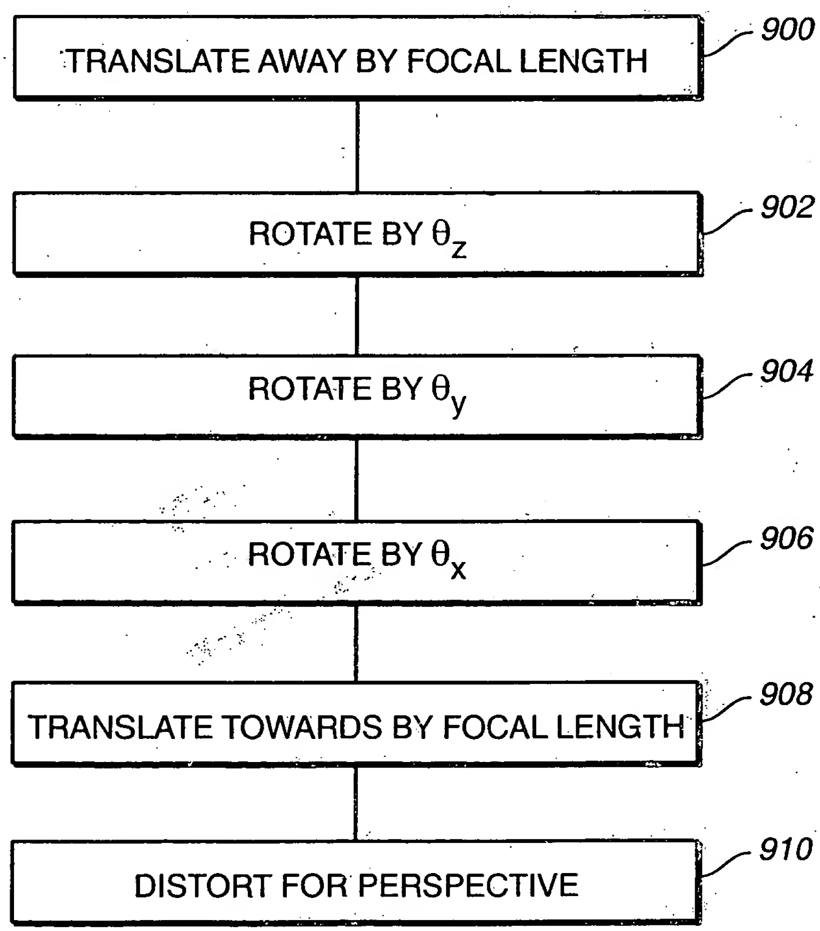

FIG._10B

Perspective Correction Transformation

1. Translate outwards:

$$T_a = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & f & 1 \end{bmatrix}$$ 136

2. Three rotations:

$$\Theta_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_x & \sin\theta_x & 0 \\ 0 & -\sin\theta_x & \cos\theta_x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$ 140

$$\Theta_y = \begin{bmatrix} \cos\theta_y & 0 & -\sin\theta_y & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta_y & 0 & \cos\theta_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$ 142

$$\Theta_z = \begin{bmatrix} \cos\theta_z & \sin\theta_z & 0 & 0 \\ -\sin\theta_z & \cos\theta_z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$ 138

3. Translate inwards:

$$T_b = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -f & 1 \end{bmatrix}$$ 144

4. Effect of focal length on Perspective:

$$P = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1/f \\ 0 & 0 & 0 & 1 \end{bmatrix}$$ 146

FIG._10C

Perspective Correction

Perspective Corrected Image Vertices given by:

$$\hat{p}_i = p_i T_a \Theta_z \Theta_y \Theta_x T_b P = \underbrace{[\hat{x}_i, \hat{y}_i, \hat{z}_i, \hat{w}_i]}_{152} \quad 150$$

But:

$$\hat{w}_i = -\frac{x_i}{f}(-\sin\theta_z \sin\theta_x + \cos\theta_z \sin\theta_y \cos\theta_y)$$
$$+ \frac{y_i}{f}(\cos\theta_z \sin\theta_x + \sin\theta_z \sin\theta_y \cos\theta_x) \quad 152$$
$$+ \cos\theta_y \cos\theta_x$$

and x_i' and y_i' from the perspective corrected image are given by:

$$x_i' = \hat{x}_i / \hat{w}_i \quad (154) \quad \text{and} \quad y_i' = \hat{y}_i / \hat{w}_i \quad (156)$$

Therefore we can write:

$$F_{xi}(\theta_z, \theta_y, \theta_x, f) - x'_i = 0 \quad 158$$

Taking:

$$t = [\theta_x \quad \theta_y \quad \theta_z \quad f] \quad 160$$

We can write:

$$-\mathbf{F(t)} = \begin{bmatrix} x_o - F_{x_o}(\theta_z, \theta_y, \theta_x, f) \\ y_o - F_{y_o}(\theta_z, \theta_y, \theta_x, f) \\ \cdot \\ \cdot \\ x_i - F_{x_i}(\theta_z, \theta_y, \theta_x, f) \\ y_i - F_{y_i}(\theta_z, \theta_y, \theta_x, f) \end{bmatrix} \quad 162$$

FIG._10D

Newton's Method

By Newton's method of numerical computation, **t** is an estimate of the values

$$[\theta_x \;\; \theta_y \;\; \theta_z \;\; f]$$

then:

$$t_{new} = t - J^{-1}F(t) \quad 166$$

is a better estimate of the values.

Where J^{-1} is the matrix of partial derivatives:

$$J_{i,j} = \frac{\partial F_i}{\partial t_j} \quad 164$$

FIG._10E

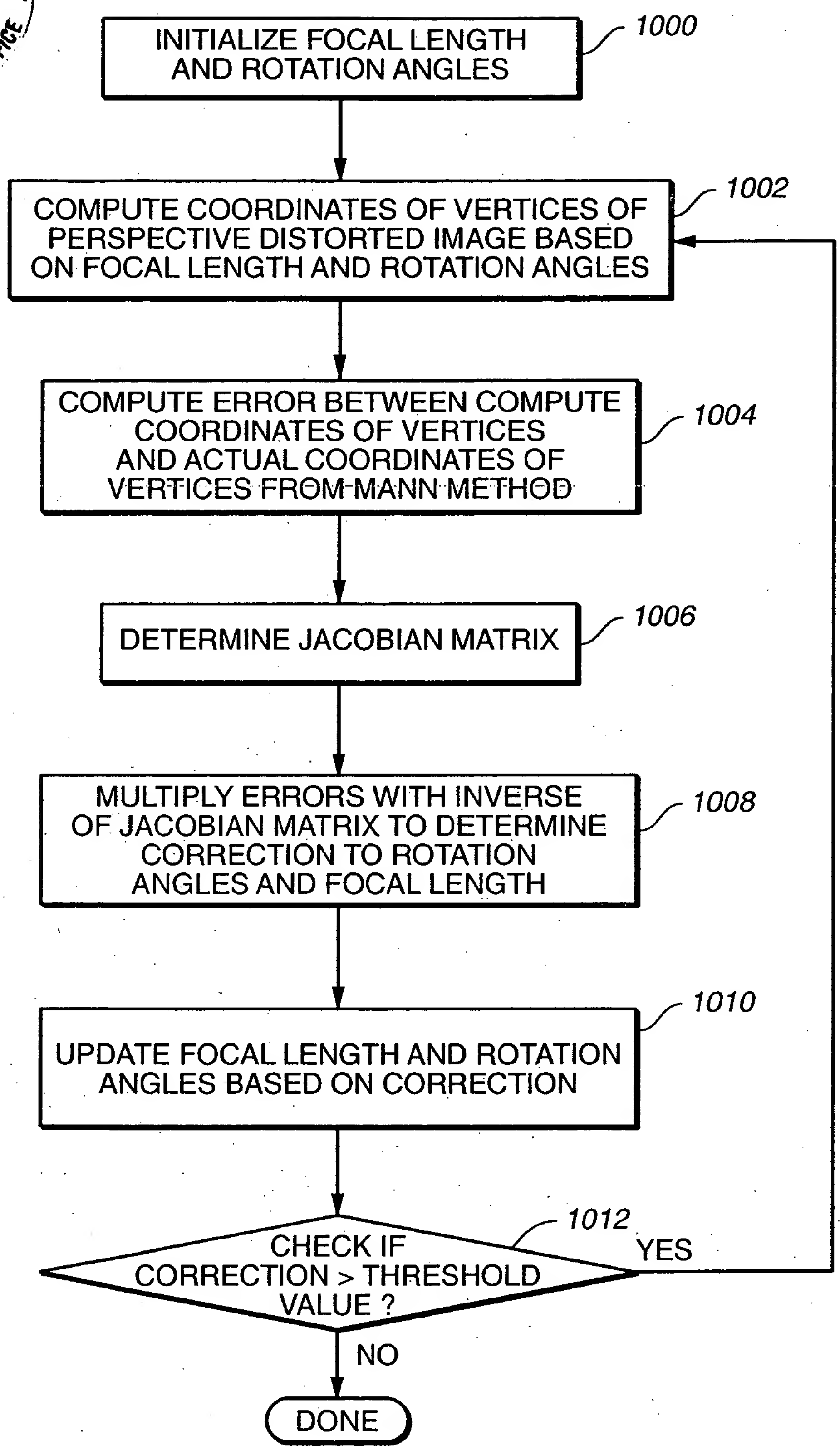
INITIALIZE FOCAL LENGTH AND ROTATION ANGLES
1000
COMPUTE COORDINATES OF VERTICES OF PERSPECTIVE DISTORTED IMAGE BASED ON FOCAL LENGTH AND ROTATION ANGLES
1002
COMPUTE ERROR BETWEEN COMPUTE COORDINATES OF VERTICES AND ACTUAL COORDINATES OF VERTICES FROM MANN METHOD
1004
DETERMINE JACOBIAN MATRIX
1006
MULTIPLY ERRORS WITH INVERSE OF JACOBIAN MATRIX TO DETERMINE CORRECTION TO ROTATION ANGLES AND FOCAL LENGTH
1008
UPDATE FOCAL LENGTH AND ROTATION ANGLES BASED ON CORRECTION
1010
CHECK IF CORRECTION > THRESHOLD VALUE ?
1012
YES
NO
DONE

FIG._11

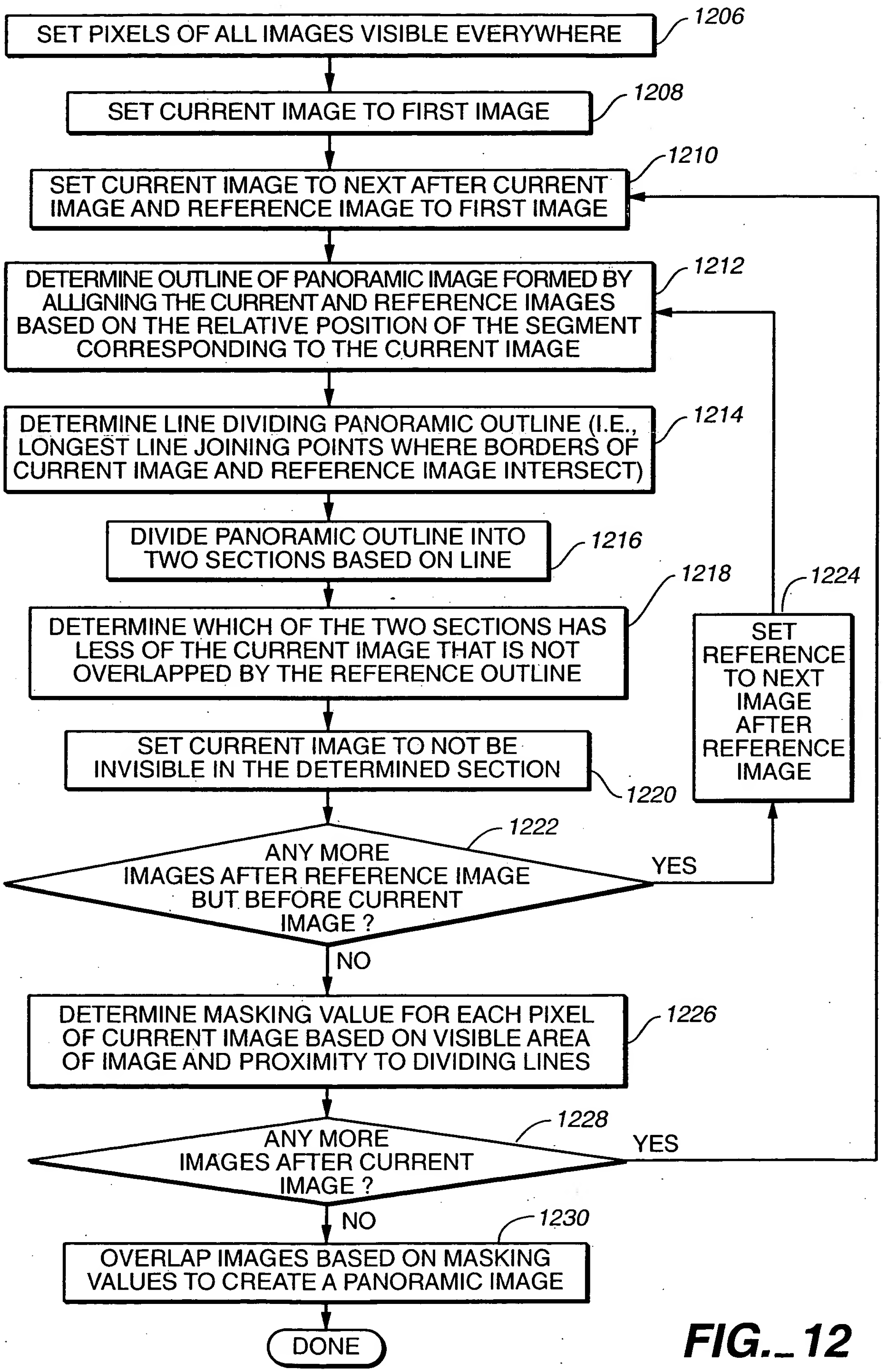
SET PIXELS OF ALL IMAGES VISIBLE EVERYWHERE
1206
SET CURRENT IMAGE TO FIRST IMAGE
1208
SET CURRENT IMAGE TO NEXT AFTER CURRENT IMAGE AND REFERENCE IMAGE TO FIRST IMAGE
1210
DETERMINE OUTLINE OF PANORAMIC IMAGE FORMED BY ALLIGNING THE CURRENT AND REFERENCE IMAGES BASED ON THE RELATIVE POSITION OF THE SEGMENT CORRESPONDING TO THE CURRENT IMAGE
1212
DETERMINE LINE DIVIDING PANORAMIC OUTLINE (I.E., LONGEST LINE JOINING POINTS WHERE BORDERS OF CURRENT IMAGE AND REFERENCE IMAGE INTERSECT)
1214
DIVIDE PANORAMIC OUTLINE INTO TWO SECTIONS BASED ON LINE
1216
DETERMINE WHICH OF THE TWO SECTIONS HAS LESS OF THE CURRENT IMAGE THAT IS NOT OVERLAPPED BY THE REFERENCE OUTLINE
1218
SET CURRENT IMAGE TO NOT BE INVISIBLE IN THE DETERMINED SECTION
1220
SET REFERENCE TO NEXT IMAGE AFTER REFERENCE IMAGE
1224
ANY MORE IMAGES AFTER REFERENCE IMAGE BUT BEFORE CURRENT IMAGE ?
1222
YES
NO
DETERMINE MASKING VALUE FOR EACH PIXEL OF CURRENT IMAGE BASED ON VISIBLE AREA OF IMAGE AND PROXIMITY TO DIVIDING LINES
1226
ANY MORE IMAGES AFTER CURRENT IMAGE ?
1228
YES
NO
OVERLAP IMAGES BASED ON MASKING VALUES TO CREATE A PANORAMIC IMAGE
1230
DONE

FIG._12